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Devonian Grossularite-Spessartine Overgrowths on Ordovician Almandine from Eastern Vermont

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Abstract

Euhedral almandine garnet ($Alm_{85}Py_7Sp_5Gr_3$) occurs in metavolcanic rocks 100 m from the intrusive contact of the Ordovician Fairlee quartz monzonite. The euhedra are rimmed by poikiloblastic overgrowths of grossularite-spessartine garnet ($Gr_{38}Alm_{34}Sp_{28}Py_{0.1}$) up to 200 μm thick. Additional reaction textures include porphyroblasts of albitized plagioclase associated with euhedral epidote, rims of sphene enclosing ilmenite, and coarse, cross-cutting flakes of white mica. The euhedral almandine garnets crystallized during Ordovician contact metamorphism caused by the intrusion of the Fairlee quartz monzonite. The grossularite-spessartine overgrowths formed during biotite-grade regional metamorphism of post-Early Devonian, pre-Triassic age.

Introduction

Plutons of the Ordovician Highlandcroft series (Billings, 1956) are intrusive into pre-Silurian metamorphosed sedimentary and volcanic rocks of eastern Vermont and western New Hampshire. Little evidence remains of the nature of the contact metamorphism that may have accompanied the intrusion of the Highlandcroft plutons because of the intensity of post-Early Devonian, pre-Triassic regional metamorphism. This paper reports on mineral assemblages believed to be relics of Ordovician contact metamorphism.

Chemical Analyses

The chemical analyses reported in this paper were made with an ARL-EMX electron microprobe at 15 kV accelerating potential using sample currents and beam diameters appropriate to minimize volatization of the analyzed elements. The following standards were employed: for Na, albite; for Mg, pyrope; for Al and Si, kyanite; for K, orthoclase; for Ca, wollastonite; for Ti, synthetic TiO_2; for Mn, spessartine; and for Fe, magnetite. Raw X-ray counts were reduced to intensity ratios corrected for deadtime, backgrounds, and drift using program CONE (Boyd, 1969, p. 63). Matrix corrections were made by the method of Bence and Albee (1968, p. 382 ff.) using the calculated and measured correction factors of Albee and Ray (1970, Table I, p. 1410; Table V, p. 1414). The precision of the analyses is 1–2 percent of the amount present, based on the variance of the count data. The accuracy of the analyses is 3 percent of the amount present, based on reanalysis of the garnets studied by Knowles *et al* (1969, p. 439 ff).

Description of Occurrence

Euhedral and anhedral almandine garnets occur in massive, chalky-weathered metamorphosed volcanic rocks 100 m west of the intrusive contact of the Fairlee quartz monzonite of the Highlandcroft Plutonic Series (Fig. 1). The volcanic rocks are probably correlative with the Ammonoosuc Volcanics (Doll *et al*, 1961). Whole-rock Rb-Sr analyses of the Ammonoosuc Volcanics give dates of 418 ± 15 m.y. (Brookins and Hurley, 1965, p. 13) or 440 ± 30 m.y. (Naylor, 1969, p. 415). The Fairlee quartz monzonite has been dated at 450 ± 40 m.y. (Naylor, 1969, p. 415).

The metamorphosed volcanic rocks have porphyroblastic, metamorphic textures; however, the bimodal size distribution of quartz and feldspar porphyroblasts (1 mm grain size) and groundmass (10–20 μm grain size) may reflect a relic volcanic texture. An indistinct schistosity is defined by the preferred orientation of white mica and biotite grains (3 × 60 μm in cross-section). Sample 70–308 (Table 1, Fig. 2) contains almandine euhedra ($Alm_{85}Py_7Sp_5Gr_3$) 2 mm in diameter that are irregularly rimmed by a poikiloblastic overgrowth of grossularite-spessartine ($Gr_{38}Alm_{34}Sp_{28}Py_{0.1}$), 0–200 μm thick. The change in

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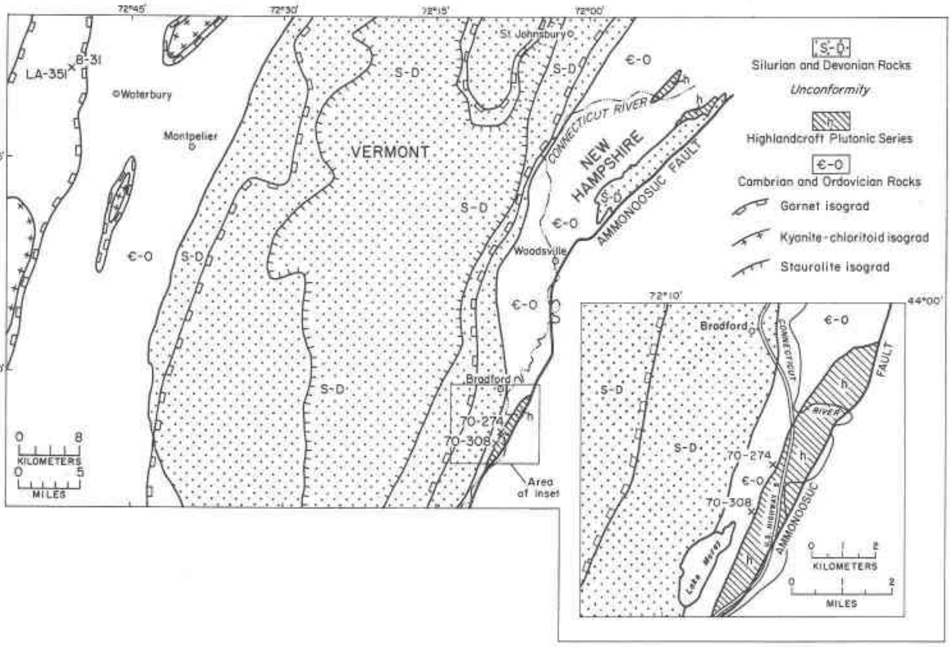

FIG. 1. Location of specimens showing evidence of Ordovician metamorphism (after Hadley, 1950; Billings, 1956; Crawford, 1966; Albee, 1968; Brown, 1969; also this study).

composition occurs within less than 5 μm measured radially from the center of the euhedra (Fig. 3). Small, euhedral garnet poikiloblasts (100 μm grain size) whose average composition is the same as that of the grossularite-spessartine overgrowth also occur in the rock (Table 1). Both the almandine euhedra and the overgrowth are slightly inhomogeneous but their composition ranges do not overlap. Additional textural relations of sample 70–308 include grains of albite (1 mm grain size) surrounded by euhedral epidote (30 μm grain size) and cross-cutting white mica porphyroblasts (200 μm grain size), that suggest the albite is a pseudomorph after more calcic plagioclase. Rims of sphene completely enclose ilmenite (80 μm grain size). The mineralogical composition of sample 70–308 in volume per cent, based on 1000 counts each on two mutually perpendicular thin sections, is as follows: albite ($An_{0.0}$), 46.3; quartz, 21.0; white mica [d(002) = 9.98 Å], 19.6; biotite, 6.7; epidote, 1.8; sphene, 1.6; small garnets, 1.1; apatite, 0.8; ilmenite, 0.6; large garnets (both core and overgrowth), 0.4; microcline, trace.

Specimens 70–274 and 70–274A, collected 2.0 km NNE of 70–308, and 100 m west of the intrusive contact (Fig. 1) contain anhedral fragments of almandine ($Alm_{87}Sp_8Py_4Gr_1$) that do not have overgrowths of grossularite-spessartine. The almandine fragments are surrounded by coarse, cross-cutting flakes of white mica and green biotite. Albite porphyroblasts are associated with euhedral epidote, rims of sphene enclose ilmenite; and pseudomorphs of felted, fine-grained white mica occur, possibly after cordierite. Chemical compositions and grain sizes of the sphene, ilmenite, and albite are similar to those of sample 70–308. Anhedral microcline porphyroblasts (Or_{100})

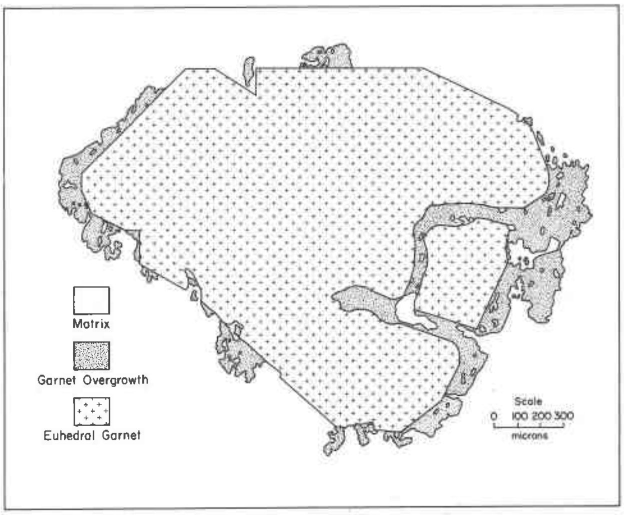

FIG. 2. Sketch of photographic mosaic of electron microprobe scanning pictures of back-scattered electrons of euhedral almandine garnet and poikiloblastic grossularite-spessartine garnet overgrowth from sample 70-308.

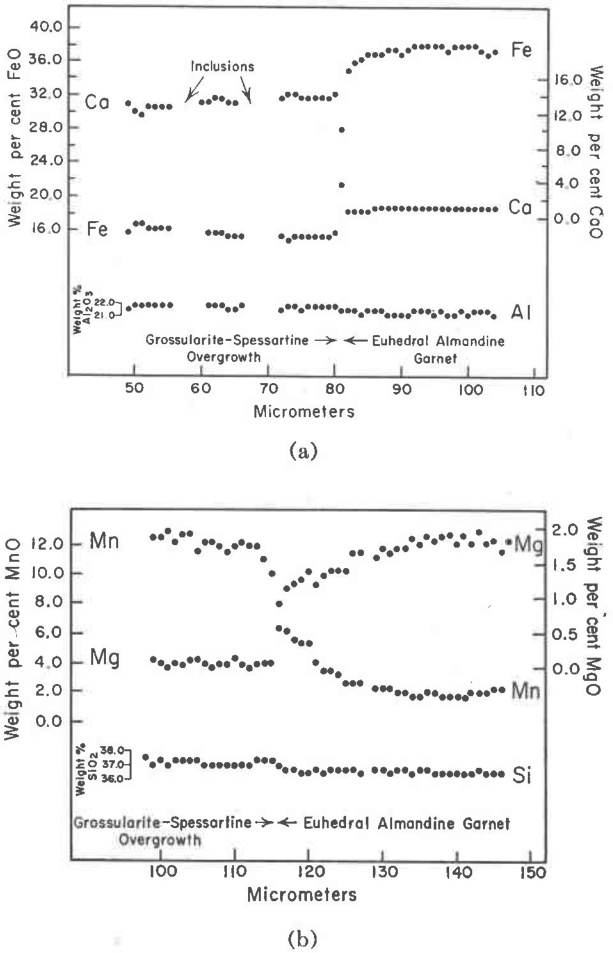

FIG. 3. Composition profiles of garnet from sample 70-308 showing discontinuous composition change from euhedral almandine core to poikiloblastic grossularite-spessartine overgrowth.

are much more abundant than in sample 70–308 and calcite is present.

Reaction Relationships

The textural relations of sample 70–308 imply that during retrograde metamorphism the rock has undergone chemical reactions in which the minerals plagioclase, ilmenite, primary biotite (?), and primary white mica (?) were reactants and the minerals albite, sphene, epidote, secondary white mica, grossularite-spessartine garnet, and secondary biotite (?) were products. The euhedral crystal faces of almandine and apatite show that they were inert during the reaction. Potassium feldspar is present in such small abundance that it probably did not participate significantly in the reaction. In order to infer the chemical nature of the retrograde reaction, it is necessary to estimate the chemical composition and modal abundance of the reactant minerals prior to retrogradation. Relics of ilmenite in the cores of the sphene-ilmenite intergrowths give the composition of reactant ilmenite and, assuming the Ti now present in sphene was derived wholly from former ilmenite, the abundance of reactant ilmenite may be calculated. Reactant ilmenite now replaced by sphene contributed 0.2 g MnO and 1.8 g FeO per 100 cc of rock as compared to 0.5 g MnO and 1.2 g FeO per 100 cc of rock contained in the grossularite-spessartine garnets, epidote, and sphene. This imbalance is probably not significant in view of the small modal abundances of the minerals involved and their inhomogeneous distribution throughout the rock. Furthermore, the FeO balance is strongly dependent on the unknown factors of reactant biotite and white mica composition. The composition of reactant plagioclase can be estimated, if it is assumed that the volume now occupied by albite was formerly occupied by plagioclase and that the rock neither gained nor lost CaO during retrogradation. The 3.5 g CaO per 100 cc of rock—now contained in sphene, grossularite-spessartine garnet, and epidote—could have been provided by a plagioclase of $An_{14}Ab_{86}$ composition. This estimate of reactant plagioclase composition requires the rock to gain 1.8 g Na_2O per 100 cc of rock during retrogradation. The following reaction relationship exists between the measured compositions of the minerals of sample 70–308 and the estimated composition of reactant plagioclase (atomic proportions):

$$\begin{aligned} &0.47 \text{ biotite} + 304.00 \text{ plagioclase} + 10.2 \text{ ilmenite} \\ &+ 9.43\, H_2O + 3.87\, Fe_2O_3 + 20.3\, Na_2O + 100 \text{ quartz} \\ &= 302.00 \text{ albite} + 2.78 \text{ sphene} + 16.10 \text{ epidote} \\ &+ 1.26 \text{ garnet} + 0.46 \text{ muscovite} \end{aligned}$$

This reaction is an approximate model of the true chemical reaction; however, because the chemical compositions of reactant biotite and white mica are unknown, it cannot be identical to the actual retrograde reaction.

Samples 70–274 and 70–274 A display textures, similar to those of 70–308, which imply that they too have undergone retrograde metamorphism. The reactant minerals in these rocks were plagioclase, ilmenite, almandine garnet, potassium feldspar, biotite (?), white mica (?), and cordierite (?). The product minerals of the reaction include albite, biotite, white mica, epidote, sphene, and calcite.

TABLE 1. Electron Microprobe Analyses of Minerals from Sample 70-308

	Euhedral Garnet Core*	Garnet Overgrowth*	Small Garnets*	Epidote*	Ilmenite	Sphene	Muscovite	Biotite
Na_2O	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.32	0.00
MgO	1.81	0.04	0.07	0.00	n.a.	n.a.	0.34	1.52
Al_2O_3	21.58	21.25	21.27	26.66	0.00	2.04	33.84	16.78
SiO_2	36.71	37.70	37.78	38.21	0.32	30.96	45.01	31.57
K_2O	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	10.76	8.42
CaO	1.13	13.21	13.29	22.10	0.31	28.38	0.00	0.07
TiO_2	n.a.	n.a.	n.a.	n.a.	53.40	37.97	0.11	1.83
MnO	1.95	12.19	12.35	0.40	3.97	0.07	0.04	0.42
FeO**	37.66	15.38	15.06	8.61***	41.33***	0.47	2.80	30.76
BaO	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.05	0.02
Total	100.84	99.77	99.82	95.98	99.33	99.89	93.27	91.39

n.a. = not analyzed.
0.00 = concentration below detectability limit (≈ 200 ppm).
* = Inhomogeneous mineral, average of at least ten spot analyses.
** = Total Fe as FeO
*** = Stoichiometry of epidote indicates 90% of Fe present as ferric iron.
Stoichiometry of ilmenite indicates less than 1% Fe present as ferric iron.

Geologic Interpretation

The primary metamorphic mineral assemblage of the garnet-bearing rocks is inferred to be plagioclase-quartz-potassium feldspar-white mica-biotite-almandine-apatite-ilmenite. This assemblage is found in both contact and regionally metamorphosed quartzo-feldspathic rocks located above the almandine isograd (Turner, 1968 p. 198 ff; p. 307 ff). The almandine euhedra may be relic volcanic phenocrysts; however, their compositions are not the same as those typical of volcanic garnets (*cf* Oliver, 1956, Table 1). Furthermore, the distribution of the garnets, occurring near the intrusive contact but nowhere else, even in volcanic rocks of similar composition, supports the hypothesis that they originated during contact metamorphism. The almandine euhedra cannot have formed during post-Early Devonian, pre-Triassic metamorphism because the nearest Siluro-Devonian rocks, located only 1.0 km west of the intrusive contact, are chlorite- and biotite-grade (Fig. 1). The nearest occurrences of almandine in Siluro-Devonian rocks are located along the almandine isograd 4.0 km to the west (Fig. 1). Therefore, the almandine euhedra crystallized during contact metamorphism caused by the intrusion of the Ordovician Fairlee quartz monzonite.

The secondary metamorphic mineral assemblage of 70–308 is albite-quartz-white mica-biotite-grossular spessartine garnet-epidote-sphene. This assemblage is widely distributed in the biotite-grade quartzo-feldspathic schists of Eastern Otago (Brown, 1967). The secondary mineral assemblage of samples 70–274 and 70–274 A is quartz-albite-white mica-biotite-epidote-sphene ± calcite. The metamorphic grade of these assemblages is compatible with that of the Siluro-Devonian rocks exposed 1.0 km west of the intrusive contact. Therefore, the grossularite-spessartine overgrowths and small garnets as well as the other secondary minerals were formed during retrogradation of the thermal aureole by biotite-grade regional metamorphism of post-Early Devonian, pre-Triassic age.

Anomalously zoned garnets reported by Albee (1968, Table 25–3, sample LA-351, p. 335) and by Brown (1969, Fig. 2, sample 8–31, p. 1663) from the Cambrian Underhill formation of central Vermont are similar to the garnets of sample 70–308 (located on Fig. 1). Spessartine-grossularite rims surround almandine cores; the change in composition is so abrupt that a Becke line is observed between the two zones (Brown, 1969, p. 1676). The assemblage in which the garnets occur is quartz-albite-epidote-muscovite-chlorite-biotite-garnet-ilmenite-rutile?-sphene?-magnetite (Brown, 1969, Table 4, p. 1668). The garnets are found in rocks that are on the low-grade side (25 km west) of the nearest almandine isograd in Siluro-Devonian rocks (Fig. 1). No outcrops of Cambro-Ordovician intrusive rocks are known in the area (Christman and Secor, 1961). Both Albee (1968, p. 330–331) and Rosenfeld (1968, Fig. 14–7, p. 196) have postulated a Cambro-Ordovician episode of regional metamorphism for the lower Paleozoic rocks of the east limb of the Green Mountain anticlinorium followed by post-Early Devonian, pre-Triassic regional metamorphism. The presence of anomalously zoned garnets supports this hypothesis to the extent that it suggests the rocks underwent prograde metamorphism followed by retrogradation. If the age of the older metamorphism can be verified as Cambro-Ordovician, then localities of anomalously zoned garnet could be used to map Early Paleozoic regional metamorphic almandine isograds.

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